RAINFALL RUNOFF MODEL FOR MOUNTAINOUS AREA BY USING HEC-HMS CASE STUDY – CAMERON HIGHLAND

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ABSTRACT

This study is focused on discharge estimation in a mountainous watershed in which three rivers at CAMERON HIGHLAND are chosen as the case study based on the rainfall distribution. The three rivers are Sg.Lemoi, Sg.Bertam and Sg.Telum. The rainfall-runoff model is simulated using Hydrological Modelling System (HEC-HMS) version 3.5. The rainfall data and stream flow data used in this study are from four rainfall stations (RF4218042, RF4414037, RF4414038, RF4514032) and two stream flow stations (SF4218416, SF4219415). The data used from the rainfall and stream flow stations are from the period of 1999 until 2014. The precision of data used during calibration and verification process depends on parameter used in HEC-HMS. Results of simulation can be generated in the form of time series table, summary table and hydrograph. Root Mean Square Error (RMSE) calculated to show the relationship of the simulated flow and the observed flow. If the RMSE value is lesser, it would indicate that the variables are positively linear related. During evaluation of model, the best value of RMSE value is $11.1m^3/s$ which is a low value. It shows that the simulated models were fit with the observed data and proves that the HEC-HMS is suitable to predict and analyse rainfall-runoff relationship at Sg. Lemoi, Sg.Bertam and Sg. Telum.

ABSTRAK

Kajian ini adalah tertumpu kepada anggaran pelepasan dalam menganjak yang bergunung-ganang di mana tiga sungai di CAMERON HIGHLAND dipilih sebagai kajian kes berdasarkan taburan hujan. Tiga Sungai ialah Sg.Lemoi, Sg.Bertam dan Sg.Telum. Model hujan-air larian adalah simulasi menggunakan sistem permodelan hidrologi (HEC-HMS) versi 3.5. Data hujan dan aliran aliran data digunakan dalam kajian ini adalah dari aliran dua aliran Stesen (SF4218416, SF4219415) dan empat stesen hujan (RF4218042, RF4414037, RF4414038, RF4514032). Data yang digunakan dari Stesen aliran hujan dan aliran adalah daripada tempoh 1999 hingga 2014. Ketepatan data yang digunakan semasa proses kalibrasi dan pengesahan bergantung kepada parameter yang digunakan dalam HEC-HMS. Keputusan simulasi boleh dijana dalam bentuk siri jadual waktu, jadual ringkasan dan hidrograf. Akar min Square ralat (RMSE) dikira untuk menunjukkan hubungan aliran simulasi dan aliran diperhatikan. Jika nilai RMSE adalah lebih rendah, ia menunjukkan bahawa pembolehubah adalah linear secara positif berkaitan. Semasa penilaian model, nilai nilai RMSE yang terbaik ialah 11.1 m ^ 3/s itulah nilai yang rendah. Ia menunjukkan bahawa model simulasi sesuai dengan data diperhatikan dan membuktikan bahawa HEC-HMS adalah sesuai untuk meramalkan dan menganalisis hubungan hujan-air larian di Sg. Lemoi, Sg.Bertam dan Sg. Telum.

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LIST OF ABBREVIATIONS

HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modelling System
RMSE	Root Mean Square Error
SCS	Soil Conservation Services
UH	Unit Hydrograph
JPS	Jabatan Pengaliran dan Salira

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The resource that cannot be created by man is water. The movement of water throughout Earth's surface, atmosphere, and underground is described as the water cycle. The processes of evaporation, precipitation, transpiration, condensation and runoff is causing the water to constantly move from one place to another. The two important processes that involve in this study will be precipitation and runoff. In Malaysia, the most common occurrence of precipitation is in the form of rain. When a part of the landscape are saturated or impervious, it leads to runoff process.

Fast response of runoff to precipitation events are specified to mountain catchments. The headwater of drainage basin are prone to create more runoff than lowland areas. Air is forced to be lifted and cooled causes mountain areas tend to get more precipitation generally. Water move downward more rapidly on steep mountainsides. There will be limited storage of water because of thinner soil on slope area and infiltration occurs in a very little amount where there is exposed bedrock. This phenomenon is called low retention capacity at high mountain area.

There are two concepts of runoff which includes infiltration –excess and saturation excess runoff. When the rainfall intensity is greater than the infiltration rate at the surface soil, overland flow occurs which is the infiltration-excess runoff. This paradigm usually found on gentle slopes because both biological activity and raindrop impact on soil surface which is continually changing. The saturation-excess runoff occurs when saturated soil surface at any further rainfall of low intensity causes runoff which lead to stream flow. This phenomenon usually occurs near existing stream channels and in depressions or hollows.

Generally, because of rapid runoff occurs at mountainous area, flash flood has become a very common problem not only all over the world but also at Malaysia. One of the biggest flood incident happened last year in Malaysia affected not only at urban catchment but also at CAMERON HIGHLAND which is a mountainous area. This has caused damage of millions of Ringgit of assets and also live of people. Although the Government has allocated money to repair the damages, but proper studies on the hydrological pattern at mountainous area is not done. But rather than that government is focusing on allocating money for the hydrological research in urban area.

Therefore, surface runoff estimation of a water shed in a mountainous area based on rainfall distribution must be done. This is a very common analysis in hydrology. There are three rivers is chosen in this study which includes Sg.Lemoi, Sg.Bertam, Sg,Telum. These three rivers are at CAMERON HIGHLAND which comply with the main criteria of this study as they have slopes. The hydrological data which includes rainfall data and stream flow data from these places helps in identifying their specific hydrological pattern.

It is vital to choose a suitable model whit simple structure, minimum input data requirement and reasonable precision is essential because measurement of all parameters affect watershed’s runoff is impossible. Therefore, HEC-HMS software is chosen which meet all these criteria and has been used widely in different hydrological studies.

1.2 STATEMENT OF THE PROBLEM

The study of runoff generation is the long standing issues on hydrology. In tropical climate, the studies on runoff and its characteristics are still scarce. The urban storm water designs applied in Malaysia mainly based on foreign experience which is the design chart of runoff coefficients in MSMA adopted from Australian data set (DID,2000). When solving hydrological problems such as flash floods in urban areas, the data may not be applicable to Malaysia and could cause failures in designing structure. Proactive measures are now taken in the process by the Government to allocate research grant for adding more information on hydrological data in urban areas.

But, mountainous area differ in hydrological pattern by the slope of the watershed. Government still not so aware on this issue. Therefore, it is vital to analysis the flood discharge pattern at mountainous area to have a better resource of information if mountainous area affected by flood which causes many damage in terms of assets and loss of people live.

1.3 OBJECTIVES OF STUDY

The main objectives of this research can be outlined below:

i. To analyse the rainfall- runoff relationship at Sg. Lemoi, Sg, Bertam, Sg.Telum.
ii. To identify the best method in analysing the rainfall- runoff relationship at mountainous area using HEC- HMS.
iii. To determine the pattern of discharge at Sg. Lemoi, Sg. Bertam, Sg. Telum.

1.4 SCOPE OF STUDY

CAMERON HIGHLAND is drained by the three main rivers which is chosen for this study namely, Sg. Lemoi, Sg. Bertam, Sg. Telum. Sg. Lemoi also known as Sg. Lemol is a stream class H (Hydrographic) located at an elevation of 354 meter above sea level. Sg. Bertam is also a stream class H (Hydrographic) located at an elevation of 29 meters above sea level. Sg. Telum also same as the other two river which is a stream clss H (Hydrographic) located at an elevation of 112 meters. The study involves taking the rainfall and stream flow data of these three rivers and simulate rainfall-runoff models by using HEC- HMS and analyse it according to the criteria needed.

1.5 THE IMPORTANCE OF THE STUDY

The rainfall runoff model is very important and necessary tools to be used in water and resource management. To forecast flood by determining the discharge pattern of an area is very important and quite difficult task. HEC- HMS software which is used to determine the hydrological changes in the study area will help in to design a better hydrological system at the mountainous area. This will decrease the amount of damage caused by flash floods at mountainous area.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Hydrology is a very crucial branch of Earth Science. Basically, hydrology is a research of the occurrences, distributions, movement and also the properties or quality of water on Earth. The hydrological cycle, water resources, and environmental watershed sustainability are the components in the scientific research. Hydrometeorology, surface hydrology, hydrogeology, drainage basin management and also water quality are the main aspects of hydrology. From the studies and researches carried in the field of hydrology, generally some of the scopes can be identified as stated below (H.M. Raghunath, 2006):

a) the frequency and the maximum probable flood that may occur at a proposed area can be determined in which to ensure the drains and culverts, dams and reservoirs, channel and other flood control structures are designed safely.
b) the frequency, quantity and also the occurrence of water in a basin can be identified to design components such as dams, municipal water supply, water power, and also river navigation.
c) the formation of soil, recharge facilities like streams and reservoirs, rainfall pattern are the knowledge of hydrology in which from developed ground water.
d) the frequency and the maximum intensity of storm to be used for the design of a drainage project in that area. .

Hydrological science plays a vital role in water resource management where the complex water systems of the Earth is analysed and in turn solves water problems that arises. This job scope is always done by hydrologists. From here, it can be clearly understood that water acts as the central element in hydrology. 70 percent or three quarter of earth's surface is covered by water which includes oceans or salt water and also fresh water that makes up the hydrosphere. From that, when divided into more specific portion, oceans or salt water makes the highest portion which is 97 percent. The remaining three percent will be further divided into 2 percent of frozen glaciers and polar ice caps, 1 percent of freshwater which 1/5 percent containing salt where it can be found in term of still water and also running water. Snow, snowfall, dew are some of the forms in which fresh water sustain its availability (P.S.Verma and V. K. Agarwal, 2000).

The importance of study or research in hydrology is getting attention at all levels of the world because of its contribution in the assessment, utilisation, development and also the management of water resources in any region. It is noted that from year 1965 until 1974, the period is recognized as the International Hydrological Decade by the United Nations. During this period of time, all the academic places such as Universities, Research Institutions and not only that, but also including Government Organisations were promoted with hydrological education research, evolution of analytical techniques and collection of hydrological information on a global range (H.M. Raghunath, 2006).

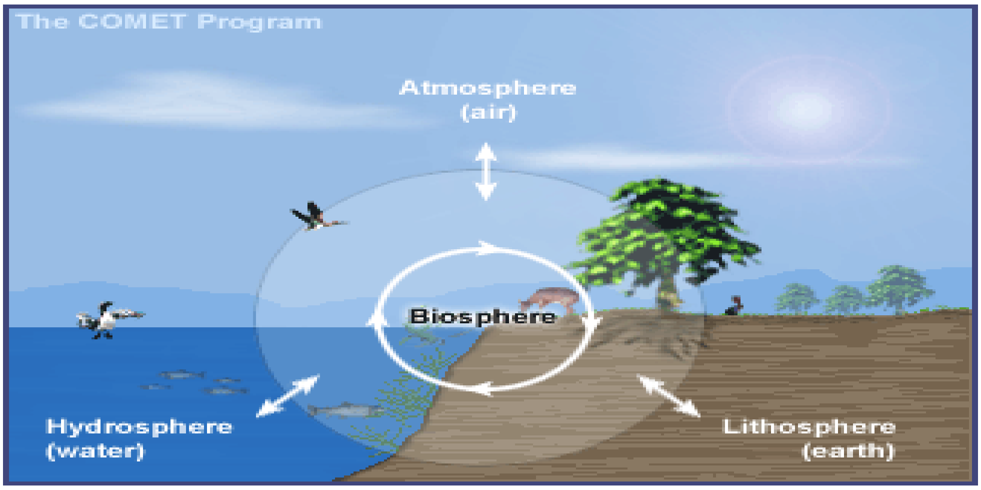

Figure 2.1: Illustration of hydrosphere

Source: UCAR 2000

2.2 HYDROLOGICAL CYCLE

The water transfer cycle occurs continuously in nature is called the hydrological cycle (H.M. Raghunath, 2006). Movement of the pathway of water in different phases through the atmosphere to the Earth, through the land, to the ocean and back to the atmosphere is called the hydrological cycle. As the total amount of water in the hydrological cycle is constant, it can be considered as a closed system for Earth (Mohammad Karamouz, Ferenc Szidarovszky and Banafsheh Zahraie, 2003). There are nine major physical processes involved in the global water cycle which forms the water movement (NWRFC, 2013). The hydrological cycle's basic characteristic is that it has no starting and no ending. The nine processes involved in the hydrological cycle are as below:

a) evaporation
b) condensation
c) precipitation
d) interception
e) infiltration

f) percolation
g) transpiration
h) runoff
i) storage

The nine processes each can have a simplified description. Evaporation is the change of physical state of water from liquid state to gaseous state. The factors that affect the amount of evaporation are solar radiation, air temperature, vapour pressure, wind and atmospheric pressure. Free water surface are one of the places in which evaporation occurs. Condensation happens when water vapour transforms into liquid state. It occurs by the cooling of the vapour or air. The energy needed for the change in state will be 600 calories of energy per gram. When all forms of water particles fall from the atmosphere to ground, it is called precipitation. The rainfall can flow over and get into stream channels through the land, penetrate into the soil, and also absorbed by plants. Interception interrupts the movement of water going to the streams. During snow time on conifer forests and hardwood forests which yet to lost their leaves, the highest level of interception occurs. When the atmosphere came in contact with soil, the water move through the boundary area in which the process is called infiltration. Percolation uses gravity and capillary forces to move the water through the soil. When water form plant evaporated to the atmosphere in the vapour form, the process is called transpiration. A liquid flow that can be seen in surface streams from a drainage basin or watershed can be called runoff. Water in the water cycle is and will be stored in the atmosphere, in the ground and also on the surface of the earth such as lakes, rivers and etc. (NWRFC, 2013).

As the study is focused on rainfall and runoff model, therefore the explanation in the following parts will be specified to these topics.

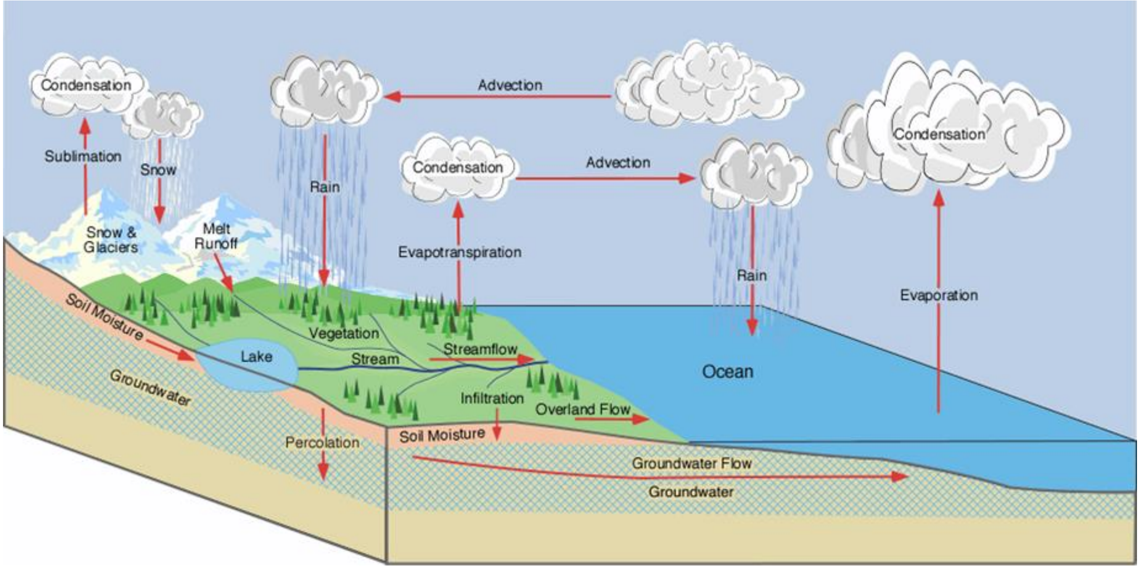

Figure 2.2: Hydrological cycle schematic diagram.

Source: Saskatchewan 2012

2.2.1 Rainfall

As mentioned previously, rainfall is one of the form of precipitation. The other form of precipitations are hail, dew, rime, snow, hoar frost and also fog precipitation. Rainfall is categorized as the liquid precipitation as the precipitation reaches the ground in the form of water droplets. The size of raindrops range usually starting from 0.5 millimetre and very hard to reach the size until 6 millimetre because heavy rain will destroy the droplets as it reaches the ground. Not only that, the velocity of a rain droplets usually ranges from 2 metre per second and can go up to 10 metre per second according to the intensity of the rainfall whether it is light or heavy (Irena I. Borzankova,).

2.2.1.1 Types of Rainfall

There are few types of rainfall and they are as below (Dr. Micheal Pdwirny, 2008):

a) Convectional Rainfall

The process occurs by convection when the moisture laden air rises because of the heating of surface layer of the atmosphere. Convection is the condition when the rising current of warm air and wide spread areas of slowly sinking airs are separated. This types of rainfall usually found year round in regions near the equator.

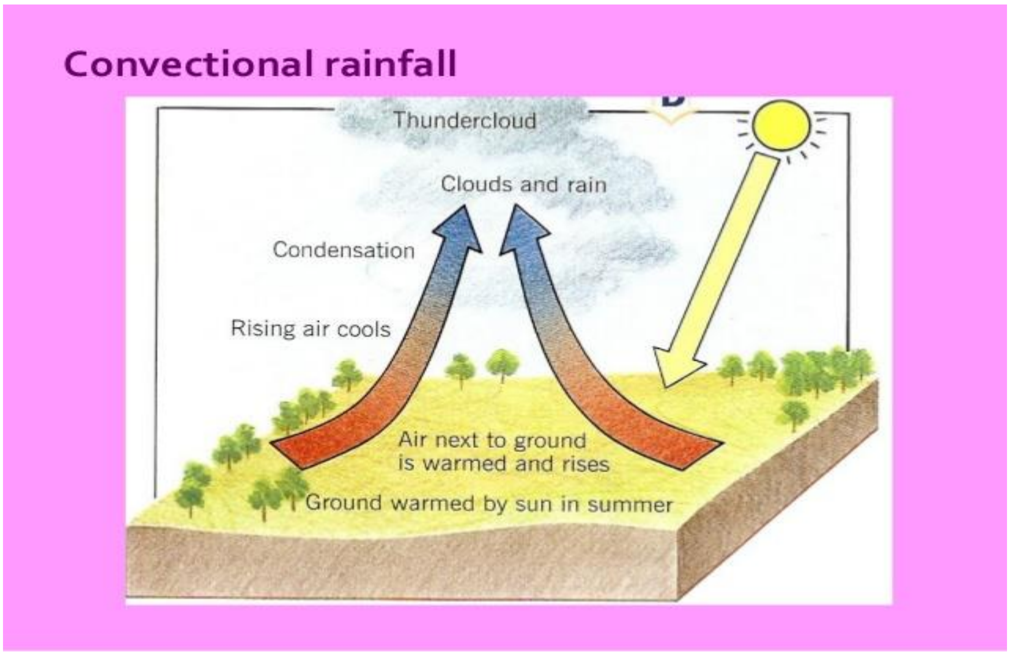

Figure 2.3: Illustration of Convectional Rain

Source: slide share, 2013

b) Cyclonic Rainfall

Depression or lows causes this type of rain to occur. When warm tropical air meets cold polar air or to be simple, when warm air overrides the cold air, the cyclonic rainfall occurs. There are two situations occur in this type of rainfall which are WARM FRONT and also COLD FRONT. Generally the rainfall is heavy but brief in duration.

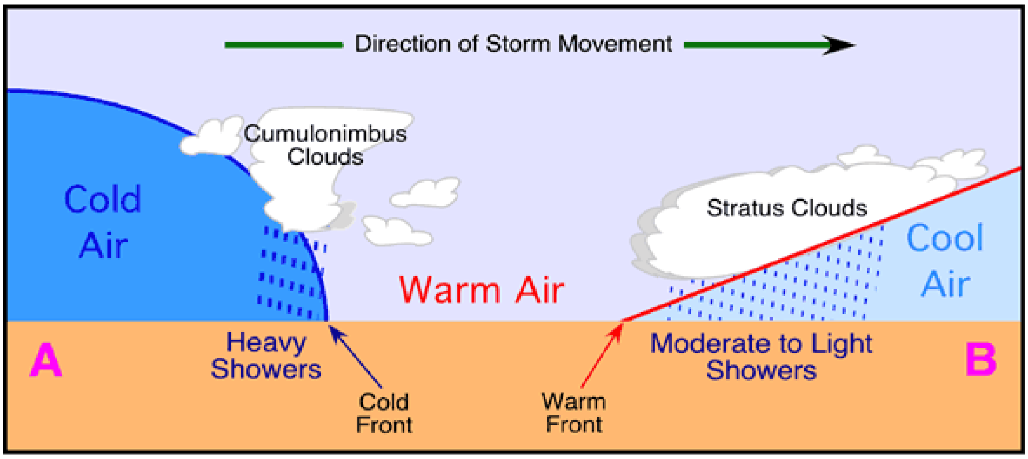

Figure 2.4: Illustration of cyclonic rainfall

Source: The Mid Latitude Cyclone, 2006

c) Orographic Rainfall

This type of rainfall occurs when a bulk of air containing water vapour is forced upwards the mountain that blocks its way. The air forced upwards expand and cools where later the water vapour condenses and rainfall occurs.

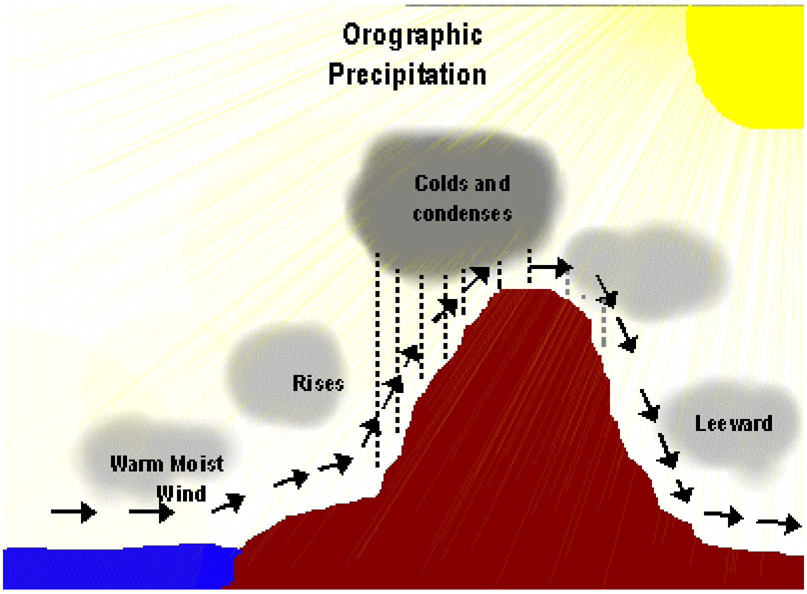

Figure 2.5: Illustration of Orographic Rainfall

Source: suprmchaos, 2012

d) Frontal Rainfall

Air masses with different temperature and density will not mix readily when they meet. Therefore, there will be front occur which is an imaginary line separating the different air masses.

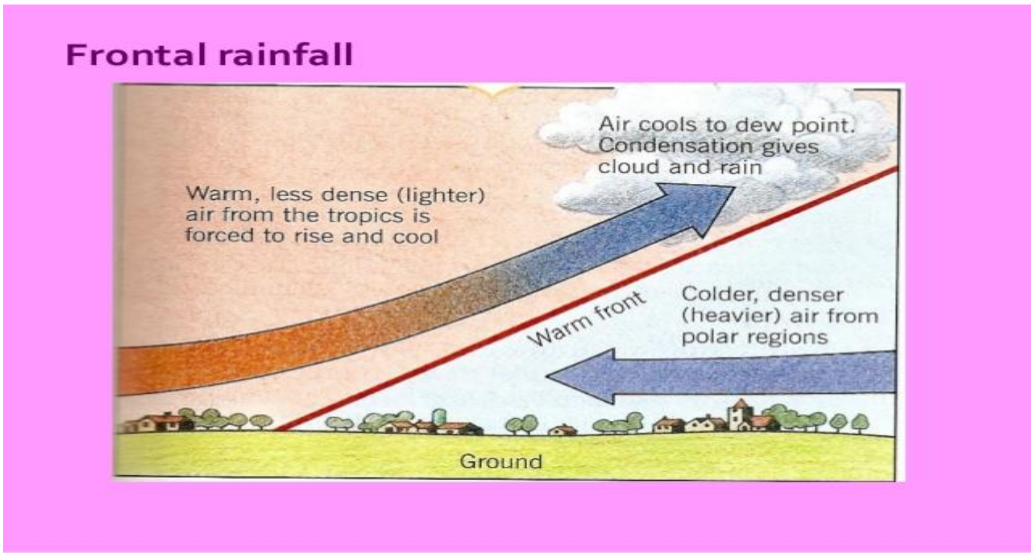

Figure 2.6: Frontal Rainfall

Source: The Mid Latitude Cyclone, 2006

e) Artificial Rainfall (Cloud Seeding)
The occurrence of rainfall by making a cloud which uses its moisture. The dry ice or silver iodide particles released and form cold clouds.

2.2.1.2 Instruments used to measure rainfall

The rainfall data can be obtained by using various types of rain gauges. The list of the types of the rain gauges are as follow (H. M. Raghunath, 2006):

a) Recording Rain Gauge
b) Weighing Type Rain Gauge
c) Tipping Bucket Rain Gauge with the recorder
d) Float Type Rain Gauge
e) Automatic- radio- reporting Rain Gauge

2.2.2. Runoff

2.2.2.1 Surface runoff

After the occurrence of precipitation especially rainfall onto the earth surface, apart from infiltration, storage, the remaining water flows according to the law of gravity and in other words, it can be said that the water flows downhill where it is called surface runoff. Surface runoff is a very important part in the hydrological cycle as it ensures the rivers and lakes are full of water, but at the same time it also damages the landscape by the act of erosion. A very big amount of water flows as runoff during storms. In 2001, the amount of runoff flowed in one day during a major storm at Peachtree Creek in Atlanta, Georgia, was 7 percent of all the stream flow for that particular year (USGS, 2014). Surface runoff or overland flow occurs when high rate of precipitation more than an abstraction. (M.J.Deodhar, 2008).

2.2.2.2 Factors affecting surface runoff

The factors affecting runoff in terms of meteorologically includes the types of precipitation which can be rain, snow, sleet and so on. Apart from that, rainfall intensity, the rainfall amount and also the rainfall duration plays key roles in affecting runoff.

In terms of factors involving physical characteristics, it includes the land use, vegetation, soil type, drainage area, basin shape, elevation, the topography especially the slope of the land, the drainage network patterns at the specific area, ponds, lakes, reservoirs and so on in the basin that prevent or delay the runoff from continuing to downhill.